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Review paper on Self healing Concrete

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Abstract- Crack formation increases the permeability of concrete to detrimental substances including different types of chemicals, gasses and water, which upon contact with concrete leads to significant impairment in various properties of concrete including strength, durability etc. Self-healing concrete is considered remedy for this durability issue. Various review papers on self-healing concrete are published. In this paper, various processes of self healing are reviewed (natural, chemical and biological). The main focus of the study is for the biological processes. This paper discusses the introduction of bacteria into the concrete, where the cracks in concrete are healed by induction of specific bacteria in mortar and concrete. This research also emphasizes on assessment of various effects of bacterial concrete on different properties of concrete, (Compressive strength, Split Tensile strength, Durability, Flexural Strength).

Key words: Self-healing concrete, Bacteria, Strength, Durability, Bio-concrete

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1. INTRODUCTION

When coarse aggregate is mixed with fluid cement it gets bonded together resulting in the formation of a blend material which is known as concrete. The fluid cement that is mixed with coarse aggregates hardens with time leading to the formation of a highly durable material. To resist the compressive load, concrete is an efficient material but the load applied on the concrete must be within the limits of resisting load of the concrete. If the load applied on the concrete exceeds the limits of resisting load, crack formation occurs in the concrete which significantly reduces the concrete strength; therefore it becomes necessary to treat the cracks which is a very expensive affair. In addition to reduction in the concrete strength, other properties of concrete like durability, permeability also gets affected.

Since crack formation results in increased permeability of concrete, therefore the water drifts easily through the concrete and affects reinforcement of the concrete structures followed by corrosion after sometime. This ultimately decreases the strength of concrete making it mandatory to repair the cracks. Low tensile strength is a very common factor responsible for crack formation in concrete. These cracks make the concrete significantly permeable to materials like water and gases containing detrimental substances and thus undermine the durability of concrete structures. If micro-crack develops on the concrete and affects the reinforcement, not only the concrete itself may be affected, but also the reinforcement will be corroded. Therefore, it is highly important to restraint the crack width so that the cracks can be healed within shortest time possible. Therefore concrete should be specially designed to heal the cracks itself, thereby introducing self healing concrete. Self-healing concrete is defined as the ability of concrete to repair its small cracks by itself. Healing cracks in concrete structure is important for its service durability and structural safety. Recently, developing self-healing concrete technology has become an important objective for researchers in biotechnology and civil engineering sciences. Among all the self-healing designing methods, biological methods are the recent ones. The various processes for the design of self-healing concrete are discussed in this paper (1) natural (2) chemical and (3) biological process.

2- SELF-HEALING CONCRETE

2.1 Natural Self-healing process

As for the natural self-healing the healing of concrete basically it takes place in certain ways as reported by **Wu *et al.*(2012).** (1) The formation of calcium carbonate or calcium hydroxide.(2) crack is blocked by impurities in the presence of water . (3) Crack is further blocked by hydration of the non reacted cement. (4) Crack is blocked by the expansion of hydrated cementitious material in the crack. In many cases, any of the above mentioned cases can occur simultaneously. This method doesn't support the fully healing of cracks. This method can be useful to prevent the development of cracks so as to prevent the penetration of harmful chemicals.

Among all the proposed self-healing mechanisms in the natural process, the first one is the most effective method to heal concrete naturally. This can be illustrated that some white residue known as calcium carbonate can be found on the outer surface of the concrete cracks and has been widely reported including **Wu *et al*.(2012)** The formation of calcium carbonate and calcium hydroxide are represented in Eqn. (1) to (3). Initially, carbon dioxide gets dissolved in water.

$$H_2O + CO_2 \leftrightarrow H_2CO_2 \leftrightarrow H^+ + HCO^-_3 \leftrightarrow 2\,H^+ + CO^{2+}{}_3 \qquad \text{Eqn. (1)}$$

Free calcium ions are released as a result of cement hydration. As a result, calcium carbonate crystals are formed. For the Reaction (2) and (3), they can only occur at pH above 8 or between 7.5 and 8. The crystals of calcium carbonate show up both at the surface of the cracks and finally fill the gap.

$$Ca^{2+} + Ca^{2-}{}_3 \leftrightarrow \quad CaCO_3 \qquad \text{Eqn. (2)}$$

$$Ca^2 + HCO_3^- \leftrightarrow CaCO_3 + \quad H^+ \qquad \text{Eqn. (3)}$$

Neville (2002) claimed that, further hydration of cementations components is mainly due to the natural self-healing properties in concrete. However, this process only applies to very young concrete and the formation of calcium carbonate most likely causes self- healing at later ages . Natural self-healing can be useful for cracks with widths up to 0.1–0.2mm

2.2.1 Hollow pipettes and vessel networks containing glue

Chemical self-healing mode for concrete can be divided into two categories: a) active mode b) passive mode. Active mode uses vessel network linked with external supply of glue for the distribution of glue whereas the passive mode uses hollow pipettes, capsules or vessel network to distribute glue that is not linked to an external glue source. It is important to select one among the above mentioned modes to design a self healing concrete. As per various researchers Hollow pipettes have been used at different length scales so as to design self healing materials. These pipettes contain glue that can be mixed with fresh concrete and will be ruptured during crack propagation and the glue is released into the cracks and finally it heals the crack. As per **Wu et al. (2012**), suitability of hollow pipettes to release glue into cracks were proven in many cases. Apart from the hollow pipette filled with glue type of self-healing concrete design, **Dry (1994)** used a vessel network within concrete for the distribution of glue. This vessel network was brittle and placed inside a concrete specimen, with one end linked to the supply of glue and the other end sealed.

2.2.2 Encapsulated glue

Encapsulation of glue is evolved from the eggs of bird (in macro-scale) or cells (in micro-scale). The size for capsules containing glue used for self-healing concrete varies from microcapsules to nano-capsules as reported by **Andalib *et al*. (2014).** Microencapsulation development starts with the preparation of capsule containing dyes. Further they are immersed into paper for the purpose of dying .It was **White et al.** who introduced the application of microcapsules containing glue for designing self-healing concrete. Usually due to the cracks microcapsules gets ruptured and this results into the release of glue into the cracks and gets filled. Micro-capsules containing epoxy resin (as glue) and acrylic resin (as a hardener) were used by **Nishiwaki (1997)** to research on the improved materials for self- healing concrete. A per him, splitting and compression tests were carried out. The results showed that: (a) two healing agents are difficult; (b) very small amount of healing agent could be filled in one microcapsule; (c) the bonding strength between the microcapsules and the cementitious matrix had to be stronger than the strength of the microcapsules. In order to solve these problems: (1) one of the healing agents might be used as core material; (2) diameter of the microcapsule should be big enough; (3) bonding strength between the encapsulated shell material and the cementitious matrix should be improved. Finally, it was concluded that there were a lot of technical problems. According to Homma, a self-healing concrete specimen containing microcapsules was loaded to the point of almost breaking. The results elaborated that; self-healing concrete specimen could recover 26% of its original strength as compared to the control specimen that recovered 10%. Based on this study, increasing the quantity of glue can raise the strength recovery ratio of self-healing concrete.

2.3 Biological self-healing process

Bacterial concrete or self-healing concrete is an efficient remedy to heal the cracks in concrete structure. Self-healing concrete is a process which makes the use of specific bacteria especially calcium carbonate producing bacteria to heal the cracks in the concrete. Calcium carbonate produced by these bacteria fills up the cracks and pores after it hardens. Small cracks i.e. crack width in range of 0.05 to 0.1 mm get completely sealed with repeated hydration. Periodic hydration leads to vicious cycle of dryness and wetness of concrete which facilitates mechanism of self-generated healing. The small cracks act as capillaries for drifting of water through the concrete during hydration and these water molecule hydrate the non or partial reacted cement resulting in its expansion which ultimately leads to filling of the cracks as was investigated by **Nishant (2016).**

2.3.1 Selection criteria of Bacteria

The bacteria which are selected to heal the cracks in the SCC should meet the criteria of surviving ability in the alkaline environment or medium. Most of the micro-organisms are not able to withstand an environmental pH of 10 or above. The bacteria which undergo a process known as sporulation, in which they form spores almost as hard as plant seeds, are the ones who possess the ability of surviving in the high alkaline environment. The spores have a very thick wall which enhances their ability to resist unfavourable conditions and are in dormant state. They get activated on coming in contact with water. Cracks in the concrete increase permeability of concrete to water due to which water transudes into the concrete structure and hence leads to activation or germination of spores. The bacterial spores germinate once the pH of highly alkaline concrete is within the optimum range of 10 to 11.5 as seen by **Luhar *et al.* (2015).**

In addition to Bacillus Subtilis, there are many other strains of different bacteria which are able to withstand the alkaline environment. Different researchers used different types of calcium carbonate precipitating bacteria in their respective studies to determine which bacteria best heals the cracks in concrete such as **Irwan *et al*.** (**2017)** used Enterococcus faecalis, Bacillus Pasturi was used by **Rana *et al.*(2017).**

2.3.2 Mechanism of Bacterial Concrete

Self-healing of cracks in the concrete occurs when non-reacted limestone and a calcium-based nutrient react biologically in the presence of specific bacteria which are introduced in the concrete. One of the bacteria used in self-healing concrete is Bacillus which uses calcium lactate as its nutrient. These bacteria can remain in dormant state for almost 200 years. These bacteria are mixed with the wet concrete while casting of concrete is being done. When crack formation occurs in the concrete, the water in the concrete mix or water from hydration percolates through these cracks as a result of increased permeability, the water molecules then come in contact with bacterial spores making conditions favourable for their germination. The spores germinate and use calcium lactate as food and undergo aerobic respiration. Calcium lactate used as food by bacteria is soluble and it gets converted into limestone which is insoluble. The insoluble limestone hardens with time and automatically fills the cracks as seen by almost every researcher. This whole process is referred to as bio-mineralization.

3. EFFECT ON COMPRESSIVE STRENGTH USING BACTERIAL CONCRETE.

Adding bacteria to the concrete is mostly for the purpose of healing. Since there is the addition of calcium lactate (acts as food for bacteria's), therefore there may be a difference in the compressive strength of concrete. The strength of the concrete increases by inducing a certain amount of bacteria in the concrete i.e., by adding 0.005 mol/l of calcium lactate with bacteria gave highest compressive strength of 42.8 MPa as seen by **Teddy *et al*. (2017).** While as it was seen the consolidation of a high number of bacteria (5.8 X 10^8 cm^{-3} cement stone) induced in concrete shown to be negative effect on the compressive strength development as bacterial concrete appeared almost weaker then normal concrete as investigated by **Gourav *et al* (2015).**

4. EFFECT ON DURABILITY OF CONCRETE USING BACTERIAL CONCRETE.

After the addition of bacteria the cracks are supposed to get healed, which in turn effects the durability of concrete. Precipitation of calcium carbonate produced by bacteria has been considered as a surrogate and eco-friendly method to improve the strength and durability of concrete. Using different proportions of Bacteria of in concrete, the durability can be tested by NaCl water (5% by weight). Results indicate improvement in durability of concrete after inclusion of bacteria. And this can be a very significant change in the durability related properties of concrete. It was also seen that the durability of bacterial concrete is more for Acid attack factor and acid durability factor by **Ardeshana *et al*. (2017).**

5. EFFECT ON SPLIT TENSILE STRENGTH OF CONCRETE USING BACTERIAL CONCRETE.

Since various bacteria can be used for the purpose of self healing in concrete. Therefore by using bacillus subtilis, which has capability of producing calcite, was cultured in the laboratory with a suitable media and was supplemented with calcium source. By using various proportions of bacteria in the concrete the result showed the increase in the split tensile strength of concrete as compared to the normal concrete. It attained a maximum value at 10^5cells/ml when added to the concrete seen by **Reddy *et al.* (2010).**

6. EFFECT ON FLEURL STRENGTH OF CONCRETE USING BACTERIAL CONCRETE.

Likewise split tensile strength, compressive strength and durability , flexural strength also shows a positive effect after inducing bacteria in the concrete. . The bacteria, used in the study as self-healing agent is Enterococcus faecalis. The results showed that by adding 0.005 mol/l of calcium lactate with bacteria gave highest Flexural strength which was obtained 6.67 MPa as compared to control concrete of 4.78 MPa by **Irwan *et al.* (2017).**

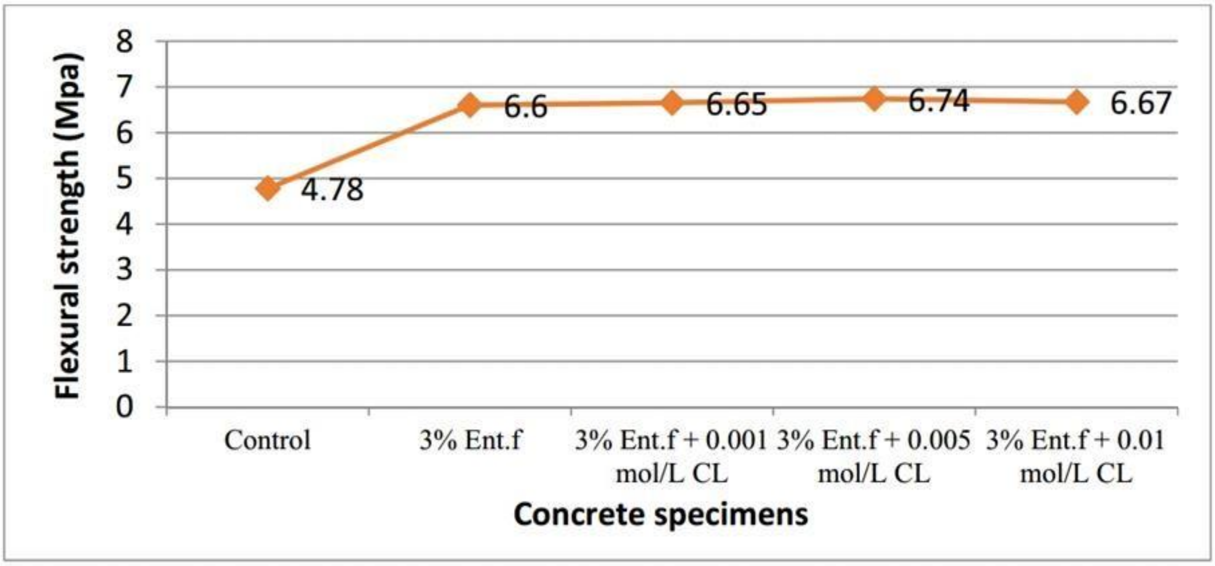

Fig 1 Comparison of different concentrations of calcium lactate on bioconcrete containing Enterococcus faecalis bacteria. [J.M. Irwan et al. (2017)]

7 CONCLUSIONS

This paper reviews a wide range of methods for designing self-healing concrete.

1. There are three possible ways of self healing concrete, namely natural, chemical and biological methods.
2. Chemical methods were the conventional methods that have been used as a sole method to design self-healing concrete.
3. This paper reviews intensively about the great potential of biological method, using the bacteria capable of precipitating calcite, as providing the way forward for developing biological self-healing concrete.
4. The precipitation of calcite will form calcium carbonate that would help in healing concrete cracks.
5. As per the research papers it can be seen that Compressive strength of the concrete increases by incorporating bacteria into the concrete by 15-30% as compared to conventional concrete.
6. Using bacterial concrete, results indicates improvement in durability of concrete. The results for durability showed that there was less strength loss and weight loss in bacterial concrete as compared to control concrete.
7. After inclusion of bacteria, the durability of bacterial concrete is more for Acid attack factor and acid durability factor.
8. Split tensile strength of concrete increases with incorporation of bacteria into the concrete by 10-20% as compared to conventional concrete.
9. Flexural strength of concrete increases by increasing bacteria into the concrete by 20-30% as compared to conventional concrete.

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